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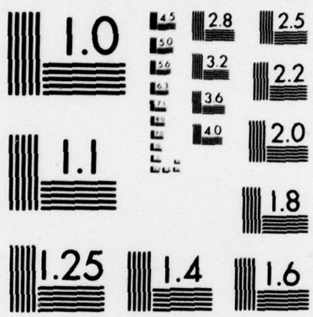
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ELECTRON TRANSPORT IN AN INHOMOGENEOUS MEDIUM REPRESENTATIVE OF THE TERRESTRIAL UPPER ATMOSPHERE

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This treatment of the electron transport in an inhomogeneous medium accounts for the pitch-angle scattering of hyperthermal electrons by neutral species and the ambient plasma. Also included is the effect of inhomogeneous character of the upper atmosphere on the relaxation length which becomes crucially important in the high magnetic latitudes. For dealing with the inhomogeneity of the atmosphere a maximum variational principle next page

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20. Abstract

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1.0 INTRODUCTION

This report contains the description of the major achievements attained during the year of 1978. The main problem considered was the development of a method which would account for the transport of electrons in the upper atmosphere in the high latitude regions where the variability of the neutral species and the ambient plasma as a function of altitude would drastically affect the final energy budget of hyperthermal electrons (e.g. photoelectrons) during the energy degradation processes.

As the relaxation length of electrons is determined by the product of the neutral species density and the appropriate collision cross-sections summed over all the species, the stopping power of the medium is characterized by the latitude dependence via the dip angle of the magnetic field. This is a consequence of the fact that the electrons are considered bound to the magnetic field lines during their gyrating motion and, therefore, their path is dictated by the magnetic field configuration. To this author's knowledge, there exists no outside literature which accounts for the effect of magnetic field configuration correctly to deal with the transport phenomenon. In this report we present the fundamental idea of how this should be done.

2.0 BASIC PARAMETERS FOR ELECTRON TRANSPORT

There are three basic quantities involved in the hyperthermal electron dynamics in the terrestrial upper atmosphere. One, the pitch angle scattering of electrons by neutral species and the small angle scattering by the ambient plasma. Importance of this quantity is summarized by stating that the pitch angle scattering is described by the probability that a given electron proceeding in some initial direction is scattered, upon an encounter with the ambient material, in some fixed prescribed direction. This is purely an atomic phenomenon and characterizes the redistribution of pitch angles which would have the effect on either confinement of electrons to a limited region of space or permit certain fraction of the electron flux to traverse along the magnetic field lines to varying latitudes and altitudes. Two, all the scattering processes which result into either pure scattering of electrons with a negligible momentum transfer to the ambient material or the inelastic scattering in which the internal states of the neutral species are excited and/or the result of the encounter is the ionization of the neutral species in which the secondary electron could be released in the continuum part of the energy spectrum. Three, the relaxation length of a hyperthermal electron of a given initial energy.

3.0 THE TRANSPORT PHENOMENON

It is a waste of time to treat the transport phenomenon if the local approximation with detailed balancing is considered as the only process important for the energy budget of the whole system. The transport implies that if one region produces electrons with a certain energy spectrum it must be calculated how those electrons affect some region of the atmosphere elsewhere. For that reason it is important to know the character of the intervening medium as to how it affects the transport as well as those of the recipient medium. The military applications of this phenomenon are quite obvious for the reason that the transport of ionization is very important to the communication systems where the radio signals must be propagated through the ionospheric structure determined by the ionization state of that medium. Therefore, the local approximations are only valid where the transport is unimportant, which means, the extreme low altitude where, in fact, the conceptual problem with regard to irregularities and inhomogeneity reduces to a triviality.

Now in the magnetospheric dynamics, the neutral species play a very little role, if any at all. But the point to be considered is in terms of the dynamics of the fields (electric and magnetic), which affect both sides; the insolated side and the magnetospheric tail. That problem needs a resolution by both theoretical and experimental verifications of the kind which measures low and high energy particle fluxes.

4.0 A SOLUTION FOR THE TRANSPORT PHENOMENON

A correlationless equation for the transport of electrons was considered with the emphasis that the earth's ionosphere provides an ideal laboratory for the hyperthermal electrons which can be described as non-self-interacting but providing the individual particle interaction with the ambient. That means that a Boltzmann type of the continuity equation is valid with the provision including the linearization of the collision integral involving the hyperthermal electrons and the ambient plasma. This restriction to the interaction with the ambient plasma should be guarded with care, in the respect, that the low energy electrons (i.e. below 3 eV) have an exchange interaction with Maxwellian tail where they become essentially indistinguishable from the thermal plasma electrons. As far as the neutral species interaction is concerned, no excitation process is to be considered below the excitation threshold energy. For the atomic oxygen, for instance, the threshold energy for exciting the 5577 Å line (Green line) is about 5 eV. Thus, a certain amount of care is necessary for accepting the results where the question of the Maxwell tail is juxtaposed to the low energies to which the hyperthermal electrons have degraded to in the final state.

Earlier we addressed the question of the neutral species density change as a function of the altitude with the confinement of electrons along the magnetic field lines, interacting with the changing density profile. Here the relaxation lengths of electrons change with the changing density profile. Our findings were that the relaxation lengths of electrons depend on the changing density profile and the corresponding cross-sections associated with the neutral species. That makes the problem of transport unconventional from the

point of view of the existing methods of treatment. We give an outline of our method which permits to deal with that problem.

5.0 VARIATIONAL METHOD

Consider the scattering processes of electrons by the medium which constitutes the upper atmosphere above about 125 kms. If x represents the relaxation length of an electron along a magnetic field line element, x is given by the sum over the product of densities and cross-section involving all kinds of interaction processes, i.e. elastic scattering, excitation and ionization and the interaction with the ambient plasma. Thus,

$$x = \int_0^s ds' \sum_I n_I \, Q_I^t(E)$$

where $Q_I^t(E)$ is the total cross-section. Here the total cross-section $Q_I^t(E)$, as a function of energy, includes the energy dependence of the impacting electron. The transport equation may be written in the form

$$\mu \frac{\partial}{\partial x} \Psi(x,\mu,E) + \Psi(x,\mu,E) = \frac{1}{2}\, \omega(x) \int_{-1}^{1} d\mu' \, f(\mu' \rightarrow \mu) \cdot \Psi(x,\mu',E) + S(x,\mu,E) \quad (1)$$

where Ψ is the number of electrons per cm^{-3} found in the energy interval dE at E in the solid angle $\mu d\phi$. The redistribution function $f(\mu' \rightarrow \mu)$ is the scattering phase function, $S(x,\mu,E)$ is the source function which is a result of the cascading of electrons by discrete energy losses and the continuous loss due to ambient plasma. Here $S(x,\mu,E)$ also contains the primary electron source. The quantity $\omega(x)$ is the most important parameter which is responsible for the elastic scattering of electrons. In fact it represents the fraction of electrons which are elastically scattered as compared to the rest of the scattering processes, such as elastic, excitation and ionization processes. The form of the cascading term $S(x,\mu,E)$ involves all the atomic processes and is complicated. However, it is

well defined. The real complication enters when one must solve Eq. (1) for the distribution function $\Psi(x,\mu,E)$ when ω is dependent on the relaxation length x. We point out that this equation is very close to the equations of radiative transfer and neutron transport. For ω independent of x, that equation has received much attention in the literature but no practical way has been found to solve it when ω is realistically posed as a function of x (the relaxation length) characterizing the atmospheric profiles.

In our attempt to solve this problem we have discovered and extended a maximum variational principle (c.f. refs. [1,2]) which is found to be most useful for obtaining the practical solutions. A discussion of the way of utilizing this principle is under preparation for extensive use in the form of a computer package and it should be available to the Air Force community. As a part of this report we include an abstract of the paper, which has been completed.

6.0 ABSTRACT OF THE PAPER

Title: "Electron Transport in an Inhomogeneous Medium Representative of the Terrestrial Upper Atmosphere"

In this paper we account for the pitch angle scattering of hyperthermal electrons by neutral species and the ambient thermal plasma. We also account for the effect of inhomogeneous character of the upper atmosphere on the electron relaxation length which becomes crucially important in the high magnetic latitudes. Thus the treatment given here embodies the physical conditions that exist in the real atmosphere. For dealing with the inhomogeneity of the atmosphere we have made use of a maximum variational principle discussed elsewhere.

7.0 FUTURE WORK

We shall use the previous work, outlined above in this report, as a basis for including the electric and magnetic fields explicitly in the calculations in the regions where these fields play an important role; such as would be the case at high altitudes and high latitudes.

8.0 REFERENCES

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